AMENDMENTS TO SPECIFICATION

On page 1, please replace the first paragraph with the following:

This application is a continuation of application Serial No 10/205,060, filed on July 25, 2002, now U.S. Patent No. 6,668,622, which is a continuation of application Serial No. 09/632,378, filed August 3, 2000, now U.S. Patent No. 6,484,567.

On page 8, line 23, please insert the following paragraph:

Fig. 11A shows an alternative arrangement for optically detecting the shear force within a sample in a parallel rheometer according to the present invention.

The paragraph starting on page 9, line 2 has been amended as follows:

In Fig. 1, merely a portion of the translational embodiment of the miniature rheometer of the present invention is shown. A moving plate ~~100~~ 102 is mounted on a shaft 101. Another plate ~~102~~ 100, which will also be referred to as the "fixed plate" even though this plate may be movable, is arranged parallel to the moving plate ~~100~~ 102. Plates 100 and 102 have surfaces which are arranged in an opposed relationship so as to be parallel to each other. The geometrical structure as well as the dimensions of the respective surfaces are selected so as to result in a desired configuration. Although the plates 100 and 102 are shown as circular elements, any other geometrical structure, such as squares or rectangles, etc., may be used for the surfaces of plates 100 and 102. Plate ~~102~~ 100 is also mounted on a shaft 103. Preferably, the shafts 101 and 103 are made of a rigid, thermally insulating material. However, any appropriate material may be used, and in some cases electrical and/or thermal conductivity of portions of the shaft 101 and 103 may be desirable. Shaft 101 is attached to an actuating element 104, which comprises a metal foil 105 which is of a rectangular shape. On at least one side of the metal foil 105, a plate of piezoelectric material 106 is attached. In this embodiment two piezoelectric plates 106 are used with the metal foil 105, however, it is also possible to use merely one piezoelectric plate on one surface of the metal foil 105. Moreover, two or more piezoelectric plates may be used in accordance with design requirements. Actuating element 104 is attached to shaft 101, preferably in a non-permanent manner, e.g. by providing a slit for receiving the actuating element 104. This permits the use of disposable plates, which in turn facilitates measurements of samples that are difficult to remove from the plates. The actuating element 104 is further attached to a mechanical assembly, which may be provided in the form of clamping blocks 107 which comprise slits for receiving end portions of the actuating element 104. A wiring assembly for applying a voltage to the piezoelectric plates 106 is also provided, but is not shown in Fig. 1. Depending on the crystallographic orientation of the piezoelectric plates 106, metal foil 105 may serve as a common electrode for applying a desired voltage to the plates 106. Alternatively, metal foil 105 may be covered by a thin, electrically-insulating layer on the middle portion, where the piezoelectric plates 106 cover the metal foil so that a voltage may be applied to the piezoelectric plates 106 by means of the electrically

conductive end portions of the metal foil 105, which are clamped in place by a clamping blocks 107, which then preferably may be made of an electrically conductive material so as to serve as electrodes.

The paragraph starting on page 10, line 1 has been amended as follows:

In this embodiment, the assembly regarding the fixed plate ~~102~~ 100 is identical to the structure referring to moving plate ~~100~~ 102, i.e. shaft 103 is attached to an actuating element 108 comprising a metal foil 109 with piezoelectric plates 110 on either side. Clamping blocks 111 are provided in order to clamp the actuating element 108 in place. Regarding electrical connections to the piezoelectric plates 110, the wiring is configured in an analogous manner as previously described with reference to plates 106.

The paragraph starting on page 10, line 8 had been amended as follows:

Fig. 2a is a schematic top view of the actuating element 104 or of the actuating element 108 of Fig. 1. For the sake of clarity only, the reference signs regarding actuating element 104 are shown. As the piezoelectric plates 106 are made of piezoelectric material, the plates 106 will undergo dimensional changes in response to an applied electric field. In Fig. 2a, the piezoelectric plates 106 are arranged such that the application of a voltage of known polarity will cause a contraction of the ~~this~~ plate along the longitudinal axis as indicated by corresponding arrows in the figure.

The paragraph starting on page 10, line 20 has been amended as follows:

Fig. 2~~b~~c schematically shows the bent actuating element 104, when the end portions thereof are clamped in place by the clamping blocks 107. The application of a voltage to the clamped actuating element 104 produces a quadruple bend that is symmetric about the center portion of the actuating element. Reversing this voltage reverses the bend. Application of an alternating voltage to the actuating element 104 therefore results in reciprocating linear translation of the center of the actuating elements as is indicated by arrow 112.

The paragraph starting on page 10, line 28 has been amended as follows:

In operation, a sample of a material of interest, preferably a material produced by combinatorial synthetic approaches, is disposed in the gap between the moving plate ~~100~~ 102 and the fixed plate ~~102~~ 100. In order to obtain well-defined experimental conditions, means may be provided to remove excess sample material, which may have accumulated during sample loading, from the edges of the plates. This is typically accomplished by providing a sharpened punch which translates and/or rotates along the plate edges so as to cut away excess material which extends beyond the edges of the plates. After having arranged the samples, which can be prepared by

molding or otherwise forming samples to the dimensions of the plates 100 and 102, the plates 100 and 102 are translated so as to be brought into contact with the formed sample. For this purpose, means are used which is not shown in the figures, but, which may, as the person skilled in the art will readily appreciate, be any appropriate mechanical assembly used in this field for translating the plates along a line normal to the opposing surfaces of the plates, so as to correctly adjust and define the distance of the gap. Alternatively, material may be placed on one plate and the other plate may be translated to a defined relative gap distance in order to mold specimens of known thickness. In this case, excess sample material is removed as previously pointed out.

The paragraph starting on page 11, line 12 has been amended as follows:

Next, a defined voltage is applied to the actuating element 104, preferably an alternating voltage with known rate and amplitude, so as to achieve a desired displacement of the middle portion of the actuating element 104, as has been explained with reference to Figs. 2a-2c. Thus, plate ~~100~~ 102 which is coupled to the middle portion of the actuating element 104 by the rigid shaft 101 is also reciprocally displaced.

The paragraph starting on page 11, line 18 has been amended as follows:

As previously mentioned, the actuating element 108 may be constructed in the same way as the actuating element 104. In this embodiment, the actuating element 108 serves as a force sensor detecting the force which is required to hold plate ~~102~~ 100 in place. For this purpose, preferably one of the piezoelectric plates ~~109~~ 110 acts as an actuating element, whereas the other one of the piezoelectric plates ~~109~~ 110 serves as a deformation sensor element. As can be readily appreciated, both piezoelectric plates ~~109~~ 110 may serve as an actuating element and an additional deformation sensor element. The deformation sensor element may be a piezoelectric plate or a conventional mechanical deformation sensor, such as a strain gage, attached to actuating element 108. The middle portion of actuating element 108 will be displaced in response to the shear force applied to the sample confined between the plates 100 and 102. This displacement is detected by one of the piezoelectric plates ~~109~~ 110 or, alternatively, by an additionally applied deformation sensing element, and is output as an electrical signal to a feedback circuitry which is not shown in the figures. The feedback circuitry, in turn, will supply a voltage to the piezoelectric plate ~~109~~ 110 which serves as an actuating element, so as to generate a force which opposes the shear force applied by the sample to the plate ~~102~~ 100. Accordingly, the feedback circuitry may be controlled such that the actuating element 108, and thus the plate ~~102~~ 100, may be maintained in an un-deflected state or any desired position when an offset voltage is added to the voltage supplied to piezoelectric plate ~~109~~ 110. Advantageously, the voltage applied to the piezoelectric plate ~~109~~ 110, which serves as an actuating element, may also serve as an output of the force sensor for determining the shear force within the sample. In comparison with traditional force sensors, this "force rebalance" sensor is exceptionally stiff, i.e. the fixed plate ~~102~~ 100

remains fixed for a wide range of applied shear forces, and hence it is possible to accurately determine the shear strain, i.e. the difference in the lateral position between the moving plate ~~100~~ 102 and the fixed plate ~~102~~ 100.

The paragraph starting on page 12, line 10 has been amended as follows:

The output of the force sensor, i.e. the actuating element 108, may then be processed in any desired manner, i.e. the voltage obtained from the force sensor may be amplified, converted into digital signals, stored in a corresponding memory, or processed by a microprocessor so as to receive required force-displacement curves, which can be related to various rheological or mechanical characteristics of the sample, wherein the dimensions of the plates 100 and 102 are taken into account. In a typical application for polymeric materials, the moving plate ~~100~~ 102 executes sinusoidal varying motions with frequencies from 0.01-1000 rad/s with an amplitude of, at most, 1% of the spacing between the plates 100 and 102. The sinusoidally-varying signal is observed at the force sensor, wherein the ratio of force waveform amplitude to the displacement waveform amplitude is related to the modulus of the material at that frequency. The existence of a difference in phase between the force and displacement waveforms implies that this modulus may be represented as a complex quantity. The real part of this complex modulus corresponds to the "elastic" or "storage" modulus of the viscoelastic material; the imaginary part corresponds to the "viscous" or "loss" modulus.

The paragraph starting on page 12, line 26 has been amended as follows:

Although the above embodiment is described using the piezoelectric actuator 104, it is also possible to employ any appropriate means for displacing the sample, such as a motorized stage, which then may preferably include a second force sensor for determining any force exerted along a line joining the centers of the moving plate ~~100~~ 102 and the fixed plate ~~102~~ 100 when the plates are positioned above one another. This type of force is usually referred to as normal force. A variety of force sensors are suitable for this purpose, in particular the piezoelectric force sensor as described above.

The paragraph starting on page 13, line 1 has been amended as follows:

With reference to ~~Figures~~ Figs. 3 and 4, a further embodiment is described which is capable of generating a rotational displacement with respect to the surfaces of a small quantity sample.

The paragraph starting on page 13, line 5, has been amended as follows:

~~Figure~~ Fig. 3 shows a perspective schematic view of a rotational embodiment of the present invention.

The paragraph starting on page 13, line 8, has been amended as follows:

Between a moving plate 300 and a fixed plate 302, a small quantity sample of a material to be characterized may be arranged. Regarding the preparation of the sample and adjusting the distance between the plates 300 and 302, the same considerations as given with respect to the translational embodiment shown in ~~Figure~~ Fig. 1 also apply in this case. Moving plate 300 is mounted on a shaft 301 which, in turn, holds an actuating element 304. Actuating element 304 is comprised of a metal foil 305 of rectangular shape. Attached to metal foil 305 are four piezoelectric plates 306, wherein two of the piezoelectric plates ~~305~~ 306 are arranged on one surface of the metal foil separated by the shaft 301 and the other two of the piezoelectric plates 306 are arranged on the other surface of metal foil 305. Thus, two of the respective ~~two of~~ piezoelectric plates 306 are arranged in an opposed relationship with metal foil 305 disposed in-between. The metal foil 305 is clamped in place by a mechanical assembly provided as clamping blocks 307.

The paragraph starting on page 13, lines 25, has been amended as follows:

~~Figure~~ Fig. 4 shows a schematic top view of the actuating element 304. Similarly, as already explained with reference to ~~Figures 2~~ Figs. 2a-2c, two opposing piezoelectric plates 306 sandwiching the metal foil 305 are electrically connected to a voltage supply in such a way that application of a voltage leads, for example, to an expansion of the upper piezoelectric plate and a contraction of the lower piezoelectric plate on the right side of ~~Figure~~ Fig. 4, and the piezoelectric plates 306 on the left side are accordingly wired so as to exhibit the inverse behavior. Thus, a central axis of the metal foil perpendicular to the drawing plane of ~~Figure~~ Fig. 4 is subjected to a rotational displacement.

The paragraph starting on page 14, line 1, has been amended as follows:

~~Figure~~ Fig. 5 shows a schematic top view of the torque sensor 308. The shaft 303, which may be made of a thermally insulating material, is attached, preferably in a non-permanent manner so as to permit the use of disposable plates, to at least two piezoelectric plates. In the present case, however, four piezoelectric plates 309 are employed and are attached to the surface of the shaft 303, such that one end of each piezoelectric plate 309 is tangential to the surface of the shaft 303. The other end of each piezoelectric plate is tethered to the rigid support 311. The crystal structure of plate 309 is aligned such that applying a voltage across the plate causes the greatest dimensional change along the line tangential to the shaft 303. As is shown, the piezoelectric plates 309 are preferably aligned along opposite sides of the shaft 303 so that the net torque resulting from the application of a voltage across the piezoelectric plates does contain a component which would tend to rotate the shaft out of its un-energized orientation.

The paragraph starting on page 14, line 14, has been amended as follows:

The torque sensor 308 further contains a sensing element, in this case in the form of the other two of the piezoelectric plates 309. The sensing element may, however, be any conventional strain gage or piezoelectric element which generates a signal upon rotation of the shaft 303. A feedback circuit which is not shown in the ~~Figure~~ figure monitors this signal and adjusts the voltage applied to the piezoelectric plates 309, which act as an actuating element, so as to rebalance the force applied to the shaft 303 and to return the shaft 303 to the un-rotated position or any desired position when a corresponding offset voltage is added to the voltage supplied to the piezoelectric plates 309. Advantageously, this voltage may also serve as a measure of the torque at the shaft 303.

The paragraph beginning on page 14, line 30, and ending on page 15 has been amended as follows:

~~Figure~~ Fig. 6 shows an alternate form of the torque sensor. In this alternative embodiment, the torque sensor 308 comprises two or more piezoelectric assemblies, each consisting of at least one piezoelectric plate 319 bounded to a metal foil 315, which are attached to the surface of the rigid shaft 303 such that one of the edges of the foil is parallel to the axis of the shaft 303 and that the other edge of the foil lies along a line perpendicular to the axis of the shaft. The edge of metal foil 315 opposite the edge in contact with shaft 303 is clamped in place by means of the rigid support 311. In the embodiment described with reference to ~~Figure~~ Fig. 5, applying a voltage to the piezoelectric plates produces the expansion or contraction of the assembly along a line tangential to the shaft 303, resulting in a torque. In this alternative embodiment, applying a voltage to the piezoelectric assembly comprising the piezoelectric plate 319 and metal foil 315 produces the buckling of the metal foil 315 and thus the rotation of the "shaft end" of the assembly about the "clamped end", also resulting in a torque being applied to the shaft 303. In this embodiment, four piezoelectric assemblies, each comprising a piezoelectric plate and a metal foil are employed. As it will readily be appreciated, more than one piezoelectric plate 319 per piezoelectric assembly may be used. Moreover, any number of piezoelectric elements may be employed, wherein advantageously at least one of the piezoelectric assemblies may be used as a deformation sensing element in combination with a feedback circuit so as to maintain the shaft 303 on its un-rotated position, thereby providing an exceptionally stiff torque sensor element.

The paragraph beginning on page 15, lines 32, and ending on page 16, has been amended as follows:

In a further variation, which is not shown in the figures, the rheometer comprises a first plate that is mechanically coupled to an actuating element such as actuating element 104 as previously described with reference to Fig. 1. However, any other appropriate actuating element which allows a translational or rotational displacement between the

first and the second plates may be used. A sensing element such as a deformation sensing element as described with reference to ~~Fig.~~ Figs. 1 – 6 may be employed to output a signal to a feedback circuit in response to the displacement of the first plate. The feedback circuit, in turn, outputs a voltage to the actuating element so as to return the actuating element to a predefined position, thereby effecting a force rebalance of the force applied to a sample confined between the first and second plates. The voltage provided to the actuating element may serve as an indication ~~for~~ of the shear stress within the sample. As can be readily appreciated, the second plate can be maintained at a fixed position, either by a second actuating element coupled to the second plate, or a fixed support holding the second plate. While the former alternative provides for the possibility to perform measurements as described with reference to ~~Fig.~~ Figs. 1 – 6 and in a way as described in this paragraph, with the same apparatus, the latter alternative obviates the necessity for a second actuating element.

The paragraph starting on page 16, line 30, has been amended as follows:

Next, with reference to ~~Figures~~ Figs. 7 – 12, a further embodiment of a rheometer is described which allows simultaneous measuring of a plurality of samples.

The paragraph starting on page 16, lines 33 and ending on page 17 has been amended as follows:

~~Figure~~ Fig. 7 shows a schematic cross-sectional side view of an exemplary embodiment of the parallel rheometer of the present invention. In ~~Figure~~ Fig. 7, a parallel rheometer 700 comprises a shear plate 701 which may contain, at predefined locations, raised regions 702 of known dimensions. Samples 703 are disposed between the shear plate 701 and a fixed plate 704 at the predefined regions. In this embodiment, the fixed plate 704 is made of an appropriate substrate carrying corresponding micromachined sensor elements. However, any appropriate fixed plate, preferably made of a rigid material such as aluminum or stainless steel, may be employed. The shear plate 701 and a fixed plate 704 are arranged parallel to one another with typical plate separations at the predefined regions of under 1mm. With each predefined region, i.e. with each sample, there is associated a sensor element 705 in order to detect a force applied to the sensor element 705 by the shear plate 701 via the sample 703. Although in ~~Figure~~ Fig. 7 a micromachined silicon force sensor is shown as the sensor element 705, any appropriate sensor may be employed, including those sensor elements that are described later with reference to ~~Figures~~ Figs. 10 – 12. The sensor element 705 has been micromachined in a silicon substrate, however any appropriate material such as silicon nitride and silicon dioxide may be used for the fixed plate 704 and the sensor elements 705.

The paragraph starting on page 17, line 17, has been amended as follows:

~~Figure~~ Fig. 8 shows a schematic top view of one rheometer element with shear plate 701 removed. The sample 703 is placed on a rectangular silicon plate of the force

sensor element 705. The rectangular plate is attached to the fixed plate 704, i.e. in this case a silicon substrate, by means of four tethers 706. The tethers 706 are equipped with piezoelectric material or any other appropriate means for sensing a deformation of the tethers 706.

The paragraph starting on page 17, line 24, and continued on page 18 has been amended as follows:

~~Figure~~ Fig. 9 is a schematic perspective view of a further embodiment of the parallel rheometer according to the present invention. In ~~Figure~~ Fig. 9, a fixed plate 904 comprises predefined regions 902 for receiving a sample of a material of interest. An array of test fixtures 901 is movably mounted on a means which is not shown in the ~~Figure~~ figure, so that the test fixtures 901 may be lowered onto the predefined region 902 and positioned at a known distance from the fixed plate 904. The text fixtures 901 acting as actuating elements may have any appropriately structured surface so as to define a required shape of the actuator-sample contact. In ~~Figure~~ Fig. 9, a cone-and-plate geometry is shown in which the actuator is a cone of known apex angle. Other geometries, however, such as a parallel plate geometry in which the actuator is a flat disk parallel to the sample surface, may be employed as well. As in the previously-described embodiment, entrainment of viscous fluids is sufficient to keep the samples confined within a column capped by the actuator and the raised regions on the fixed plate 904. The test fixtures 901 are individually coupled to respective motors 910 via respective encoders 911. Advantageously, the predefined regions 902 contain respective force sensor elements.

The paragraph starting on page 18, line 6 has been amended as follows:

Again referring to ~~Figures~~ Figs. 7 and 8, a strain field is generated across each sample by attaching the shear plate 701 to a translation stage 710 ~~which is not shown in the Figures~~. This translation stage 710 moves in the plane of the plate-sample contact at a controlled rate so as to approximate a sinusoidal displacement of a required amplitude and frequency. The fixed plate 704 remains fixed in position, resulting in a shear field extending through each sample. Appropriate translation stages providing the required displacement with appropriate amplitude and frequency are well-known to those skilled in the art.

The paragraph starting on page 18, line 19 has been amended as follows:

In the embodiment described with reference to ~~Figure~~ Fig. 9, the motors 910 are actuated to provide a rotational displacement which may be provided to the samples in the form of a sinusoidal displacement of a desired amplitude and frequency or in the form of a continuous, i.e. a non-reciprocating shear at a defined shear rate. Compared to the translational embodiment described with reference to ~~Figures~~ Figs. 7 and 8, the rotational embodiment permits measurements under steady, shear conditions and can

also be configured to operate as a controlled stress rheometer, as will be described below.

The paragraph starting on page 18, line 27, has been amended as follows:

The translational embodiment as well as the rotational embodiment ~~include~~ includes a shear stress sensor at each sample position. One version of this sensor element is described with reference to ~~Figures~~ Figs. 7 and 8 and consists of a micromachined silicon rectangle which is tethered to the surrounding silicon substrate by four micromachined silicon tethers. The surface of the rectangle lies in the plane of the surrounding silicon surface. Applying a shear stress to this rectangle by any of the means as described above generates a piezoelectric response in the four silicon tethers which can be detected by conventional electronic means such as a resistance bridge. Any variations in the geometry of this sensor element may be performed so as to permit it to be optimally used in all of the embodiments described above, i.e. the number of tethers, the shape of the silicon plate for receiving the sample, the location of the individual tethers, etc. may be adapted to the type of displacement required.

The paragraph starting on page 20, line 25, has been amended as follows:

In further variation, either plate can include one or more or an array of coils which generate a magnetic field across each sample. Alternatively, the entire parallel rheometer may be placed between the poles of a large magnet or a pair of Helmholtz coils. In this case, the devices surrounding the sample, i.e. the shear plate 701 and the fixed plate ~~705~~ 704 or 904 have to be constructed of a non-magnetic material in order to avoid eddy currents associated with the motion of the plates. Again, measurements may be made as a function of field amplitude, field frequency, the rates of change of these two quantities, time at a given value of these two quantities, or a combination of two or more of these criteria.

The paragraph starting on page 21, line 1, has been amended as follows:

Preferably, in the embodiments having electrodes or coils generating a magnetic field, a force sensor element may be employed that is immune to electromagnetic noise, such as the sensor elements described below. However, the electronic sensor as described above with reference to ~~Figures~~ Figs. 7 and 8 may, nevertheless, be used as well.

The paragraph starting on page 21, line 18, has been amended as follows:

~~Figure~~ Fig. 10 is a schematic perspective view of the first embodiment of a stress-optic sensor according to the present invention. In ~~Figure~~ Fig. 10, an optical fiber 1001 is attached to a block of stress-optic material 1002. The bock 1002 is made of suitable sensor material, including transparent plastics such as polymethyl methacrylate,

suspensions of liquid crystals in a polymeric matrix, and certain silica glasses. A fixed plated 1003, preferably made of a rigid material such as stainless steel or aluminum is attached to the block 1002 in order to receive a sample. Opposed to fiber 1001 is a second fiber 1004 which is optically coupled to a detector element 1005. Fiber 1001 serves as an input fiber and is designed as a single mode optical fiber allowing the propagation of linearly polarized light. Accordingly, only linearly polarized light will enter block 1002, and the polarization direction of the input light will be changed in conformity with the shear force applied to the sample which is indicated by the arrow in ~~Figure~~ Fig. 10. Preferably, optical fiber 1004, acting as an output fiber, is also designed as single mode fiber with its polarization direction selected such as to be perpendicular to the polarization direction of the light output by fiber 1001. Preferably, the stress-optic material of block 1002 is prepared so as to exhibit zero birefringence in the absence of stress. Hence, substantially no light will be output by fiber 1004 and input into detector element 1005 when no shear stress is applied to a sample on plate 1003. Application of stress to the sample and thus to the sensor element alters the polarization of the light transmitted to block 1002 and produces a measurable signal at detector element 1005. The signal increases with increasing shear stress applied to the sample.

The paragraph starting on page 22, line 15, has been amended as follows:

~~Figure~~ Fig. 11 schematically shows a further embodiment of a stress-optic sensor element according to the present invention. In ~~Figure~~ Fig. 11, a light source 1101, preferable a laser, emits linearly polarized light. The light emitted by light source 1101 passes through a half-mirror 1102 and is input into a multimode fiber 1103. A block of stress-optic material 1104 is attached to the other end of fiber 1103. The end block 1104 opposing the fiber 1103 is provided with a sample plate 1105 which is preferable made of a rigid material such as stainless steel or aluminum which is capable of reflecting light. Above sample plate 1005, a "moving" plate 1106, acting as an actuator, is positioned such that a sample 1107 is confined between sample plate 1105 and actuator 1106. In this embodiment, actuating element 1106 and sample plate 1105 exhibit a cone-and-plate geometry, however, any other appropriate geometry such as a parallel-plate geometry may also be used as previously mentioned. Further, in the optical path of light reflected by half-mirror 1102, a polarizing element 1108 id disposed in front of a detector 1109.

The paragraph starting on page 23, line 10, has been amended as follows:

Alternatively, referring to Fig. 11A, light from the light source 1101 is transmitted ~~though~~ through a circular polarizer 1102b. Circularly polarized light is then introduced into the optical fiber and is guided to the stress optic material and reflected back by the sample plate. The polarization state of the light is altered due to the stress induced in the stress-optical material by shear applied to the sample by the actuating element. The reflected light having an altered polarization state due to its interaction with the stress-optic material is partly transferred back through the circular polarizer 1102b.

Hence detector 1109b (positioned beside light source 1101) will detect a light intensity in response to the shear force prevailing in the stress optic material.

The paragraph starting on page 23, line 27, has been amended as follows:

In a further embodiment not shown in the ~~Figures~~ Figs., using a single mode ~~fiber optic the input fiber~~ optical fiber as the input, the sensor material and the output fiber are combined into a single length of a single mode optical fiber ~~optic~~. Applying a shear stress to a "sensor" section of this optical fiber ~~optic~~ rotates the polarization direction of the light passing through it due to the "stress optic" characteristics of the sensor section, as previously pointed out. The output section of this single mode optical fiber ~~optic~~ transmits only that portion of the light which has a polarization direction parallel to that transmitted by the input section. Thus, the intensity of light exiting the output section decreases with increasing shear stress applied to the sample. Quantitative measurements may be facilitated by comparing the output of this single mode optical fiber ~~optic~~ to that transmitted by a second, unstressed length of a single mode optical fiber ~~optic~~.

The paragraph starting on page 24, line 16, had been amended as follows:

With reference to ~~Figure~~ Fig. 12, an improved force sensor element is described which allows the simultaneous measurement of a shear force and a normal force.

The paragraph starting on page 24, line 19 has been amended as follows:

In ~~Figure~~ Fig. 12, a recess portion 1201 is formed in a substrate 1202 comprising silicon or any other appropriate material such as silicon nitride or polyimide, etc., by standard micromachining manufacturing steps such as photolithography and etching. Within the ~~recesses~~ recessed portion 1201, a rectangular plate 1203 is formed which is tethered by four tethers 1204, 1205, 1206, and 1207 to the substrate 1202. Each of the tethers 1204-1207 comprises two regions that have piezo-resistive properties, which are shown as "N-doped" regions as indicated by "n" in the ~~Figure~~ figure. The tethers 1204 and 1207 are electrically connected by a wiring line 1208 which, in turn, is electrically connected to contact pads 1209 and 1210, respectively. Similarly, tethers 1205 and 1206 are electrically connected by a wiring line 1211 which, in turn, is electrically connected to contact pads 1212 and 1213, respectively. ~~Figure~~ Fig. 12 is not to scale and the width of the tethers 1204-1207 is exaggerated in comparison with the side length of the plate 1203. In a preferred embodiment of the force sensor according to the present invention, the width of the tethers is about 80 μm and the side length of plate 1203 is in the range of one to several mm. The length of the tethers is about 1mm and the length of a single piezo-resistive area, i.e. of any N-doped regions in the surface layer of each tether, is about 300 μm.

The paragraph starting on page 25, line 10, has been amended as follows:

In operation, an input voltage is applied to the contact pads 1209 and an output voltage is obtained at contact pad 1210 which represents the middle terminal of a piezo-resistive bridge formed by the respective N-doped regions of the tethers 1204 and 1207, respectively. Similarly, an input voltage, possibly of the same amount as that applied to contact pads ~~1203~~1209, is applied to contact pads 1212 and an output voltage can be detected at contact pad 1213 which represents the middle terminal of a piezo-resistive bridge formed by the respective N-doped regions on the tethers 1205 and 1206, respectively. When a shear force is applied to the plate 1203, i.e. a force which, in the configuration of ~~Figure~~ Fig. 12, is substantially oriented in the plane of the plate 1203 and normal to the axes of the tethers 1204-1207, so as to cause a slight displacement of the plate 1203, thereby generating a deformation of the tethers 1204 to 1207. The N-doped regions of tether 1207 are mirror-symmetrically arranged with respect to a vertical middle axis of plate 1203 so that the change in resistance of the tethers 1204 and 1207 will substantially cancel out each other. Accordingly, the voltage detected at contact pad 1210 substantially remains unchanged.

The paragraph starting on page 26, line 1, has been amended as follows:

Similarly, when a force is applied to the plate 1203 which is directed perpendicular to the drawing plane of ~~Figure~~ Fig. 12, the tethers 1204-1207 are deformed in such a way that the output voltage on contact pad 1210 is maximally shifted depending on the magnitude of displacement of plate 1203 in the direction perpendicular to the drawing plane, whereas the output voltage detected at contact pad 1213 remains substantially unchanged, irrespective of the magnitude of the displacement. Accordingly, the tethers 1204 and 1207 act as a normal force sensor element.

The paragraph starting on page 26, line 10, has been amended as follows:

Although the force sensor which is able to simultaneously detect a shear force and a normal force has been described with reference to the embodiment as shown in ~~Figure~~ Fig. 12, a variety of modifications may be performed still providing the same advantages as the embodiment described above.

The paragraph starting on page 26, line 27, has been amended as follows:

Moreover, in order to provide a stiffer behavior of the sensor element in responding to the shear force, it may be advantageous to arrange the tethers and doped regions thereon in such a way that the shear force is applied in the longitudinal direction of the tethers. For this case, tether 1207 of ~~Figure~~ Fig. 12 will be doped as is shown in the ~~Figure~~ figure and tether 1206 will be doped as tether 1204 of ~~Figure~~ Fig. 12, wherein contact pads 1209 and 1212 are electrically connected so as to serve as a middle terminal of the normal force resistant bridge. The shear force bridge formed of tethers 1204 and 1205 include, respectively, at least one doped region, wherein contact pads 1209 and 1212 are connected to serve as a shear force output. An input voltage

common to the shear force sensor bridge and the normal force sensor bridge is applied at the contact pads 1210 and 1213.

The paragraph starting on page 27, line 11, has been amended as follows:

The preferred layout of N-doped piezo-resistor regions shown in ~~Figure~~ Fig. 12 is preferably aligned along the direction of maximum tension and preferably along the direction of maximum change in piezo-resistance, to get maximum sensitivity. For the embodiment shown in ~~Figure~~ Fig. 12, the 100 direction is the direction of both maximum tension and maximum piezo-resistance change. Although the use of N-doped regions is shown, all N-doped regions may be replaced with P-doped regions. Also, the device alternatively may have different orientations of the piezo-resistor. For example, a P-doped piezo-resistor would preferably be aligned along the 110 direction, at 45 degrees to the direction of longitudinal forces for maximum sensitivity. In alternative embodiments for the ~~Figure~~ Fig. 12 embodiment of this invention, the N-doped regions may be replaced with any suitable piezo-resistive element, for example, piezo-resistive metal wires or doped polycrystalline silicon.